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FREE-RETURN TRAJECTORIES TO VENUS BETWEEN 1976 AND 1980

By Benjamine J. Garland

Advanced Mission Design Branch

MISSION PLANNING AND ANALYSIS DIVISION

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FIGURES

FREE-RETURN TRAJECTORIES TO VENUS

BETWEEN 1976 AND 1980

By Benjamine J. Garland

SUMMARY

A study was made of the free-return trajectories to Venus between 1976 and 1980. The characteristics of these trajectories are similar to the characteristics of free-return trajectories to Venus between 1970 and 1975. The total trip times are between 322.5 and 403 days. An injection velocity of 12 760 fps or less is required to obtain a 30-day launch window at each launch opportunity. The entry velocity at Earth is between 42 800 and 45 140 fps.

Free-return trajectories are not physically possible prior to some departure date during each launch opportunity. Free-return trajectories before this time require periapsis altitudes below the surface of Venus.

INTRODUCTION

The results of a detailed study of free-return trajectories to Venus which begin between 1970 and 1975 were presented in reference 1. It is probable that the earliest manned interplanetary mission will not occur until after 1975. This report presents the characteristics of free-return trajectories to Venus between 1976 and 1980 as an extension of the study presented in reference 1.

SYMBOLS

r	distance between body and the center of the Sun, AU
v	velocity, fps
λ	longitude of body in heliocentric ecliptic coordinate system, deg

λ_p	longitude of body in planet-centered coordinate system, deg
ξ	right ascension of hyperbolic excess vector, deg
ρ	distance of body from the center of the planet, ft
ϕ	latitude of body in heliocentric ecliptic coordinate system, deg
ϕ_p	latitude of body in planet-centered coordinate system, deg
ψ	declination of hyperbolic excess vector, deg

ANALYSIS

The method used to calculate the free-return trajectories has been presented in references 2 and 3. The ephemerides of the planets are described by non-coplanar ellipses whose elements vary with time. The orbital elements of the planets were obtained from reference 4.

The two coordinate systems used, the heliocentric ecliptic system and the planet-centered system, are shown in figure 1. The position of a body in the heliocentric ecliptic system is given by the distance from the center of the Sun (r), the longitude (λ), and the latitude (ϕ). The latitude is the angle between the ecliptic plane and the position vector of the body. The longitude is the angle between a line from the center of the Sun to the autumnal equinox and the projection of the position vector of the body into the ecliptic plane.

The planet-centered coordinate system moves with the appropriate planet but is oriented parallel to the heliocentric ecliptic system. The position of a spacecraft in the planet-centered coordinate system is given by the distance of the spacecraft from the center of the planet (ρ), the longitude (λ_p), and the latitude (ϕ_p). The velocity of the spacecraft is specified by the magnitude of the velocity (v), the right ascension (ξ), and the declination (ψ).

In the case of free-return trajectories to Venus, it was shown in reference 1 that there might be a maximum value of the periapsis altitude at the target planet. The value of the maximum altitude depends upon the departure date from Earth. It is not possible to achieve a free-return trajectory to Venus before certain dates because the maximum periapsis altitude will lie below the surface of the planet. In other words, the beginning of a launch opportunity may be dependent on more than the required injection velocity.

The conversions between Julian dates and the Gregorian calendar during the time periods discussed are given in the table.

RESULTS

The first group of free-return trajectories occurs between 2 443 115 JD (December 3, 1976) and 2 443 195 JD (February 21, 1977). Some of the characteristics of trajectories with periapsis altitudes at Venus of 0 and 1000 n. mi., are presented in figures 2(a) through 2(d) as functions of the departure date, which is given as both the Julian date and the Gregorian calendar date. Free-return trajectories with a periapsis altitude of 0 n. mi. at Venus are not possible before 2 443 115 JD, and it is not possible to obtain a periapsis altitude of 1000 n. mi. at Venus until after 2 443 120 JD. For convenience, each launch opportunity will be considered to begin when a periapsis altitude of 1000 n. mi. is possible.

The injection velocity and the entry velocity at Earth are presented in figure 2(a). The injection velocity is the difference between the perigee velocity of the escape hyperbola and the circular velocity at perigee. The perigee altitude was assumed to be 262 n. mi. for all the trajectories considered. The injection velocity is affected only slightly if the periapsis altitude at Venus is changed from 0 n. mi. to 1000 n. mi. In general, the injection velocity is decreased no more than 50 fps when the periapsis altitude is changed from 0 to 1000 n. mi. The minimum injection velocity is approximately 11 540 fps and occurs when the departure date is 2 443 156 JD. The required injection velocity is below 11 800 fps for 30 days beginning 2 443 140 JD and ending 2 443 170 JD. This is an increase of only 260 fps above the minimum required injection velocity. The entry velocity at Earth is between 43 800 fps and 44 530 fps for all the trajectories in this time period. If the periapsis altitude at Venus is increased from 0 n. mi. to 1000 n. mi., the entry velocity at Earth will be increased approximately 150 fps.

The outbound trip time and the total trip time are presented in figure 2(b). The outbound trip time varies between 81 and 145 days and the total trip time varies between 335 and 405 days. An increase in the periapsis altitude from 0 to 1000 n. mi. will cause an increase of approximately 1 day in the outbound trip time and approximately 7 days in the total trip time.

The magnitude and direction of the hyperbolic excess vector at departure from Earth are presented in figure 2(c). The minimum value of the hyperbolic excess is 9600 fps. The declination of the hyperbolic excess vector varies between 0.5° and 25.0°, and the right ascension varies between -2.0° and 29.0°. Neither the declination nor the right ascension are affected greatly by increasing the periapsis altitude from 0 to 1000 n. mi.

The periapsis velocity of the spacecraft at Venus and the angle between the periapsis position vector and the line connecting the centers of Venus and the Sun (spacecraft-Venus-Sun angle at periapsis) are presented in figure 2(d). The periapsis velocity at Venus, which varies between 33 000 and 38 000 fps, depends more on the periapsis altitude than on the departure date from Earth. The periapsis velocity is decreased approximately 4000 fps if the periapsis altitude is increased from 0 to 1000 n. mi. In comparison, the periapsis altitude increases approximately 1000 fps if the departure date is delayed from 2 443 120 JD to 2 443 215 JD while the periapsis altitude is held constant. The spacecraft-Venus-Sun at periapsis is between 10° and 22° of the subsolar point.

The characteristics of free-return trajectories to Venus beginning in 1978 and 1980 are presented in figures 3(a) to 3(d) and 4(a) to 4(c), respectively. The minimum injection velocity in the 1978 time period is 11 470 fps, but in 1980 the minimum injection velocity has increased to 12 140 fps for a periapsis altitude of 0 n. mi. An injection velocity of approximately 11 640 fps is required to obtain a 30-day launch window in 1978 while an injection velocity of 12 760 fps is required to achieve the same launch window in 1980. The entry velocity at Earth is between 42 800 fps and 43 280 fps in 1978 and between 44 810 fps and 45 140 fps in 1980. The outbound trip times vary from 71 to 133 days, and the total trip times vary between 322.5 and 384.5 days. The velocity of the spacecraft at the periapsis at Venus is between 34 000 fps and 38 500 fps. The periapsis at Venus lies between 10° to 18° of the subsolar point.

The characteristics of the trajectories between 1976 and 1980 do not differ significantly from those presented in reference 1 for trajectories between 1970 and 1975. The reason for this small variation is that the orbits of Earth and Venus are almost circles. If both orbits were circular, there would be no variation between launch opportunities.

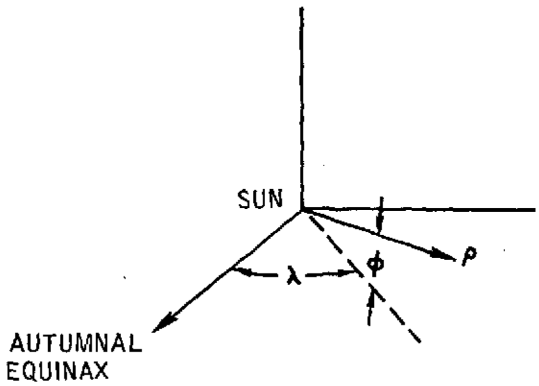
The characteristics of dual-planet, free-return trajectories to Venus and Mars in 1978 were presented in reference 5. It was not possible to obtain a 1000-n. mi. periapsis altitude at Venus with this type of trajectory. The minimum injection velocity for the dual-planet trajectories occurs approximately 110 days after the minimum injection velocity for the trajectories to Venus in 1978. The minimum injection velocity for the dual-planet trajectories is 14 200 fps instead of 11 470 fps for the trajectories to Venus alone. The entry velocity at Earth is between 2500 to 10 000 fps higher for the dual-planet trajectories than for the Venus trajectories, and the periapsis is located on the dark side of the planet near the terminator instead of near the subsolar point. The total trip times of the dual-planet trajectories are approximately twice the total trip time for the Venus trajectories.

CONCLUDING REMARKS

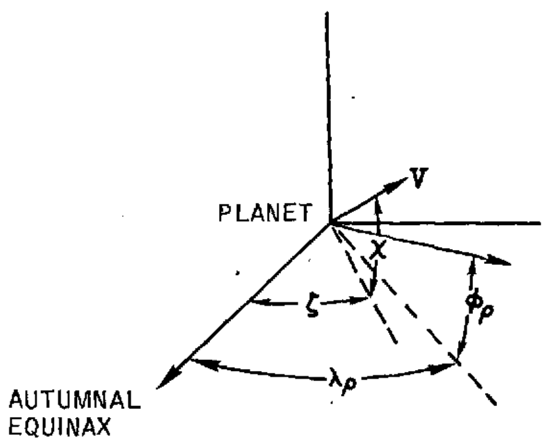
The characteristics of free-return trajectories to Venus between 1976 and 1980 are similar to those of free-return trajectories to Venus between 1970 and 1975. A spacecraft which is capable of achieving free-return trajectories to Venus between 1970 and 1975 will also be capable of achieving free-return trajectories to Venus for any launch opportunity through 1980. It was stated in reference 5 that a spacecraft which is capable of achieving free-return trajectories to Mars in 1977 and 1979 will also be capable of performing dual-planet free-return trajectories to Venus and Mars in 1978. Such a spacecraft will be capable of free-return trajectories to Venus between 1970 and 1980.

CONVERSIONS BETWEEN JULIAN DATES AND GREGORIAN CALENDAR DATES

Julian date	Gregorian calendar date
2 443 100	November 18, 1976
2 443 120	December 8, 1976
2 443 140	December 28, 1976
2 443 160	January 17, 1977
2 443 180	February 6, 1977
2 443 200	February 26, 1977
2 443 700	July 11, 1978
2 443 720	July 31, 1978
2 443 740	August 20, 1978
2 443 760	September 9, 1978
2 443 780	September 29, 1978
2 443 800	October 19, 1978
2 444 300	March 2, 1980
2 444 320	March 22, 1980
2 444 340	April 11, 1980
2 444 360	May 1, 1980
2 444 380	May 21, 1980
2 444 400	June 10, 1980

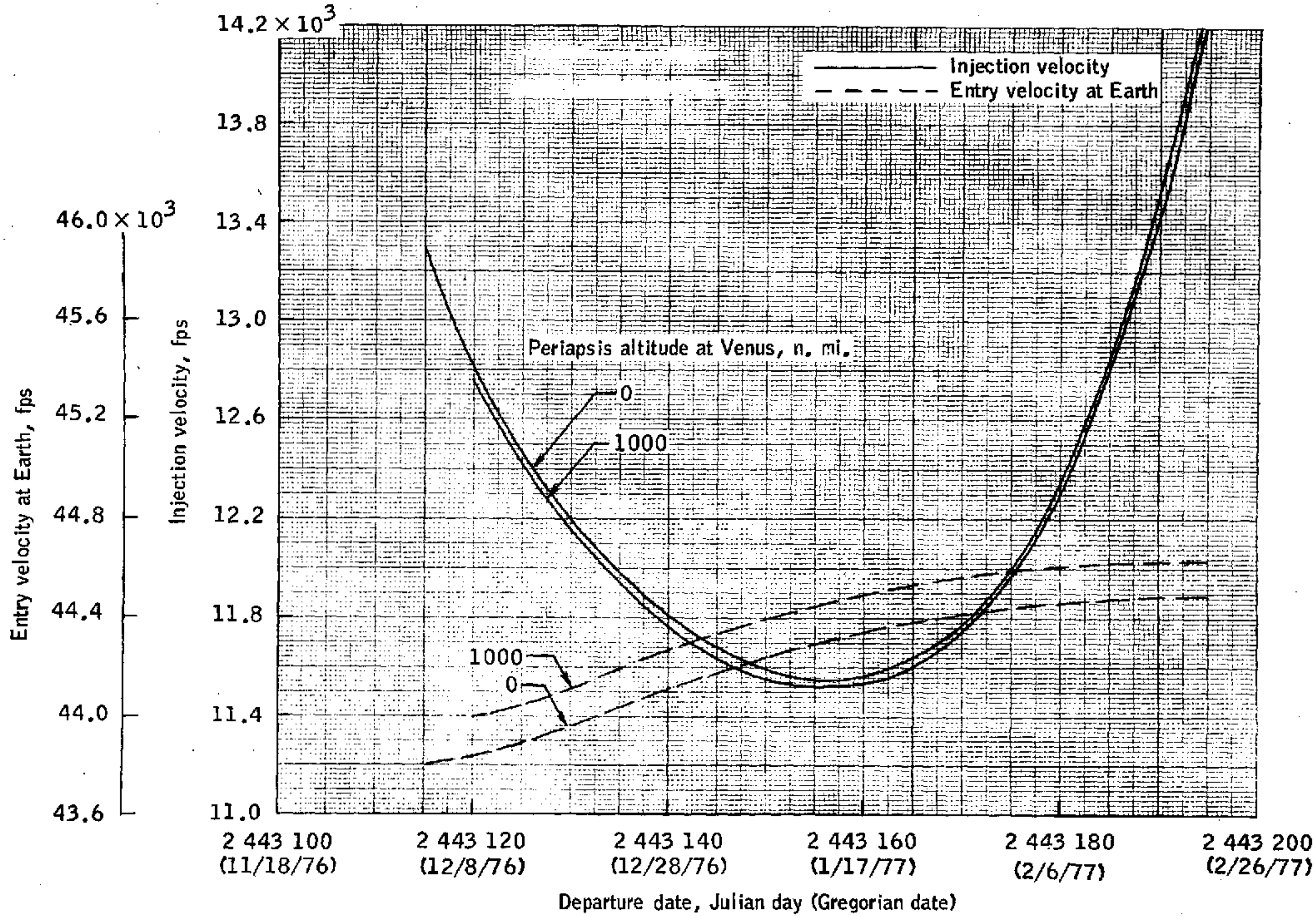


(a) Heliocentric-ecliptic system



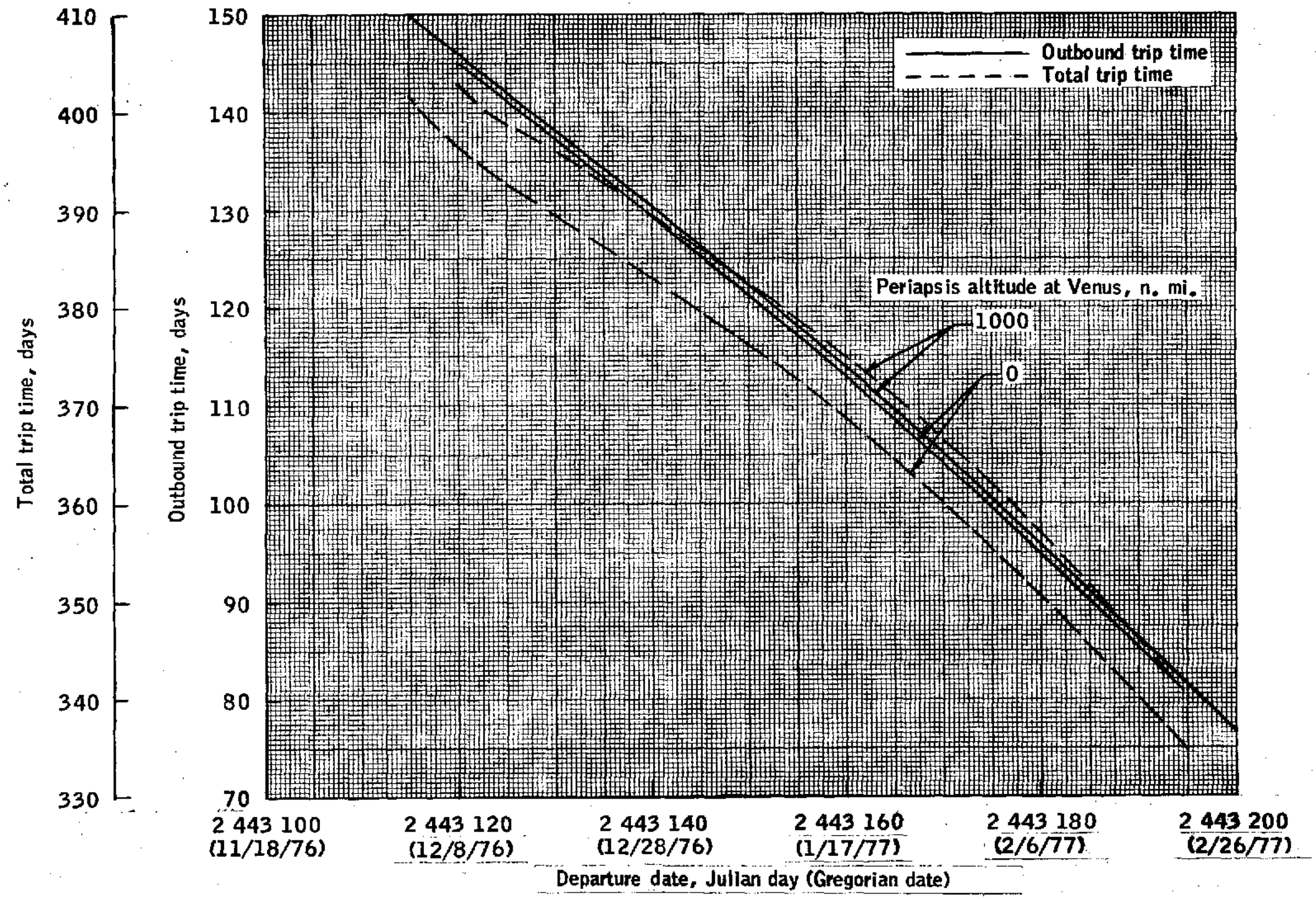
(b) Planet-centered system

Figure 1.- Heliocentric-ecliptic and planet-centered coordinate system.



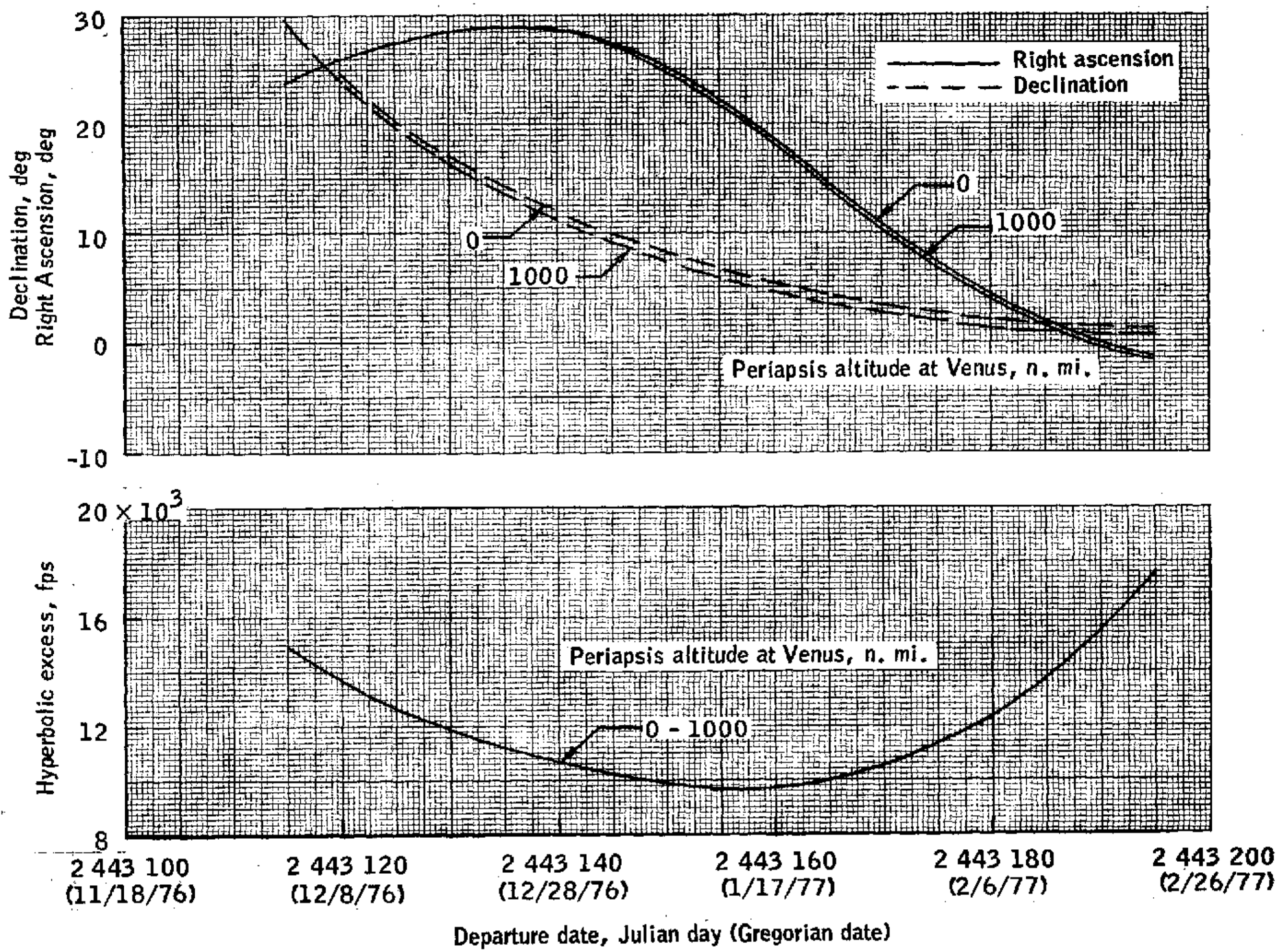
(a) Injection velocity and entry velocity at Earth.

Figure 2.- Characteristics of free-return trajectories to Venus between November 18, 1976 and February 26, 1977.



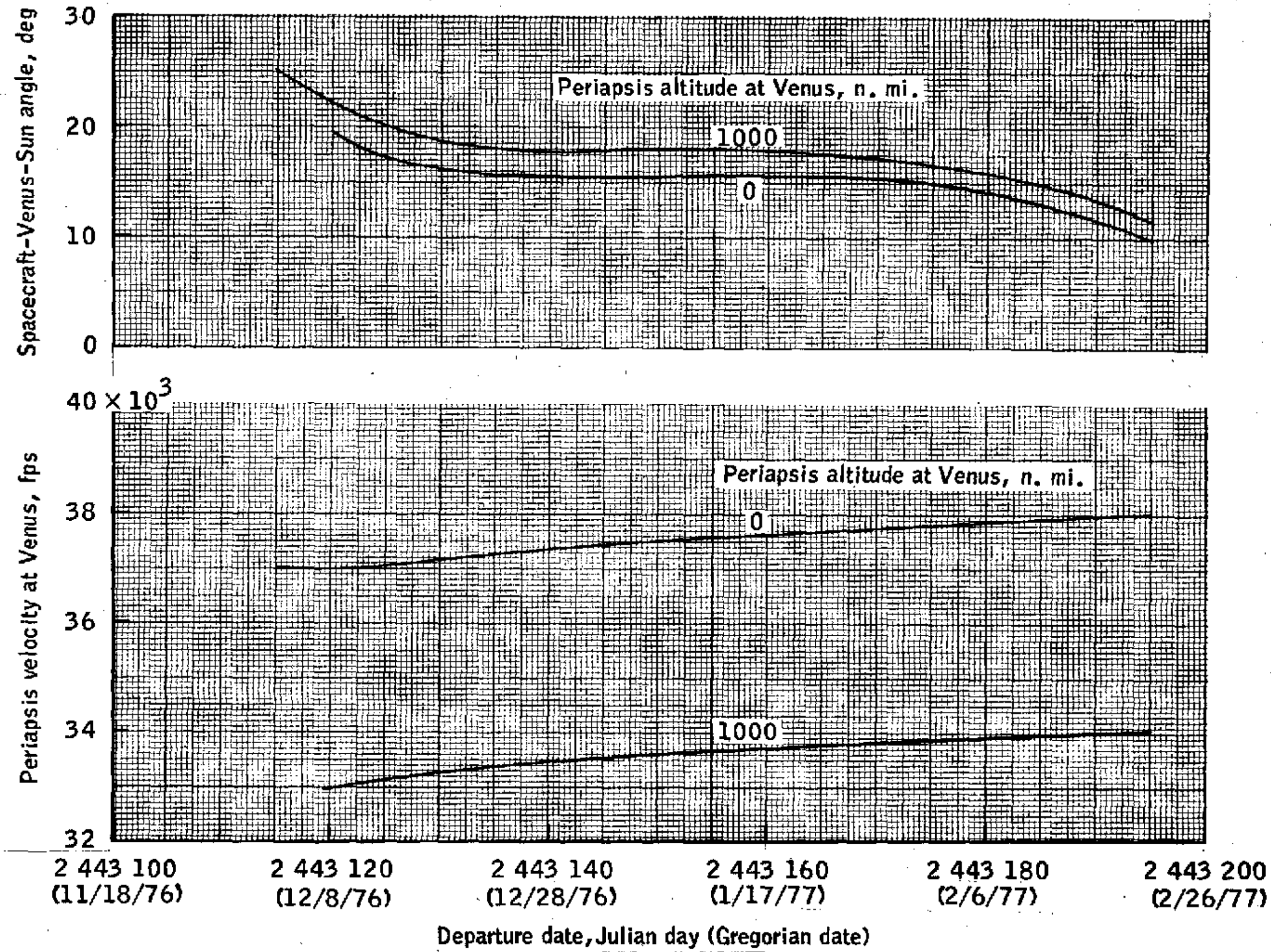
(b) Outbound trip time and total trip time.

Figure 2.- Continued.



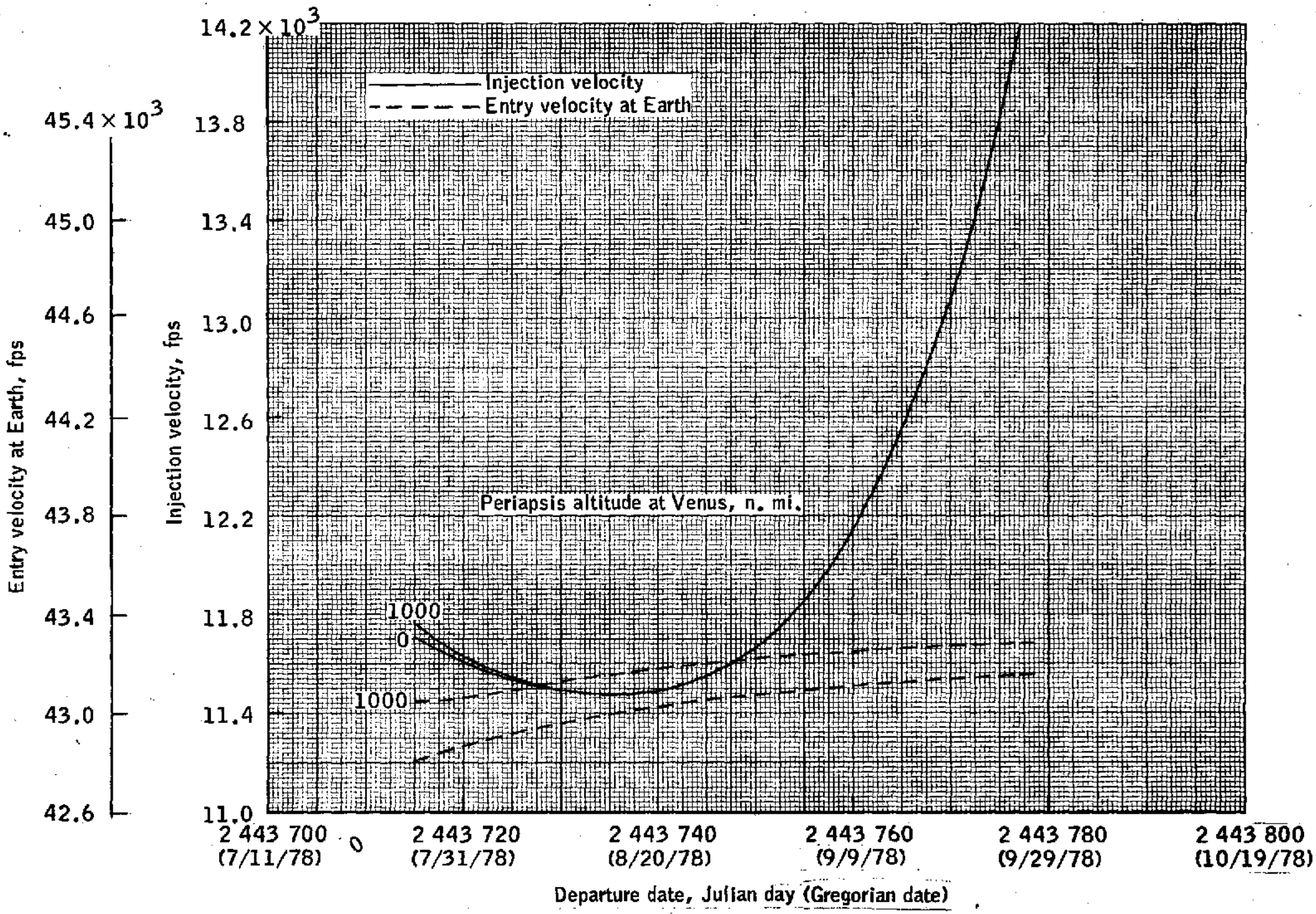
(c) Direction and magnitude of hyperbolic excess vector at departure from Earth.

Figure 2.- Continued.



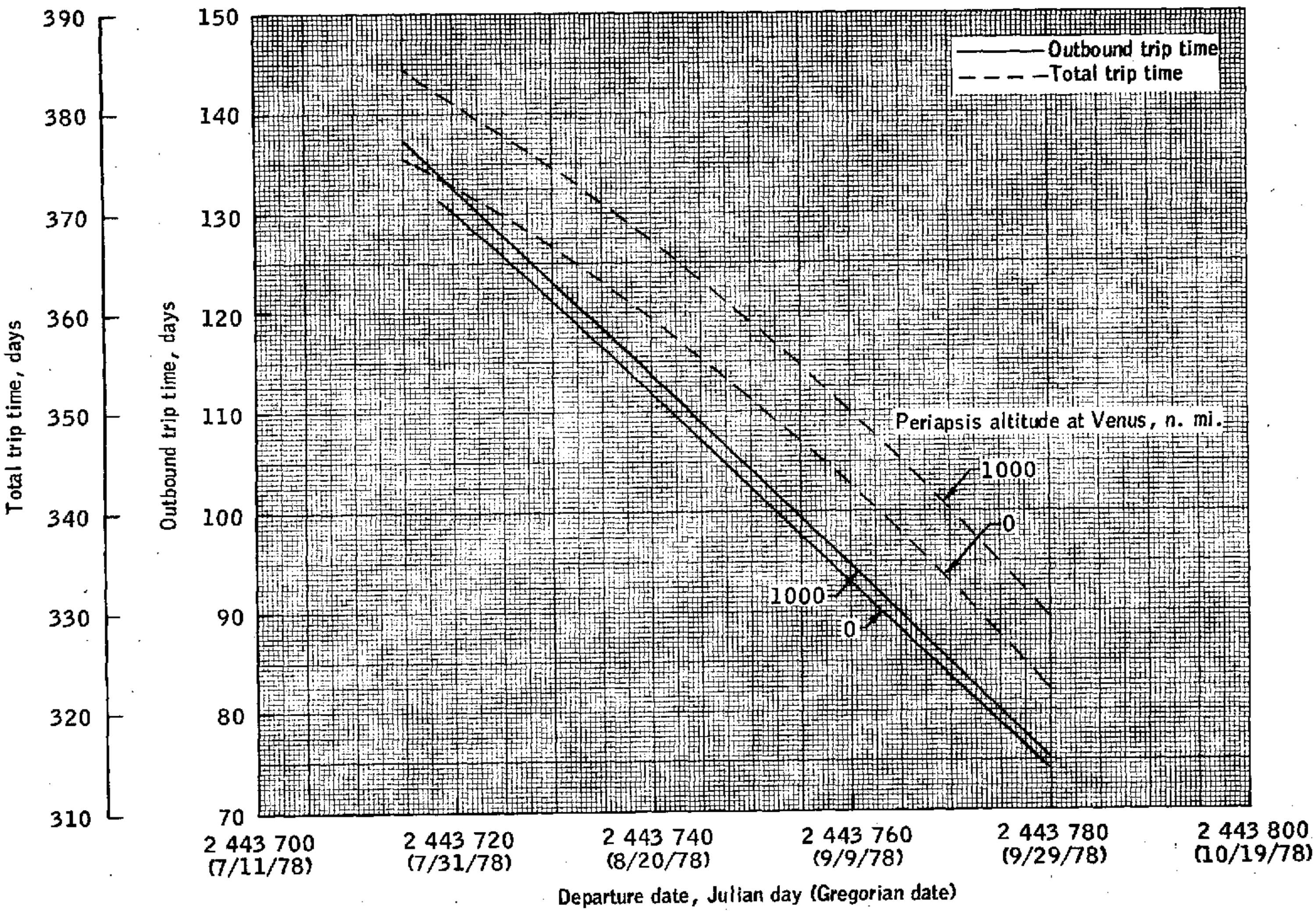
(d) Periapsis velocity at Venus and spacecraft-Venus-Sun angle at periapsis.

Figure 2.- Concluded.



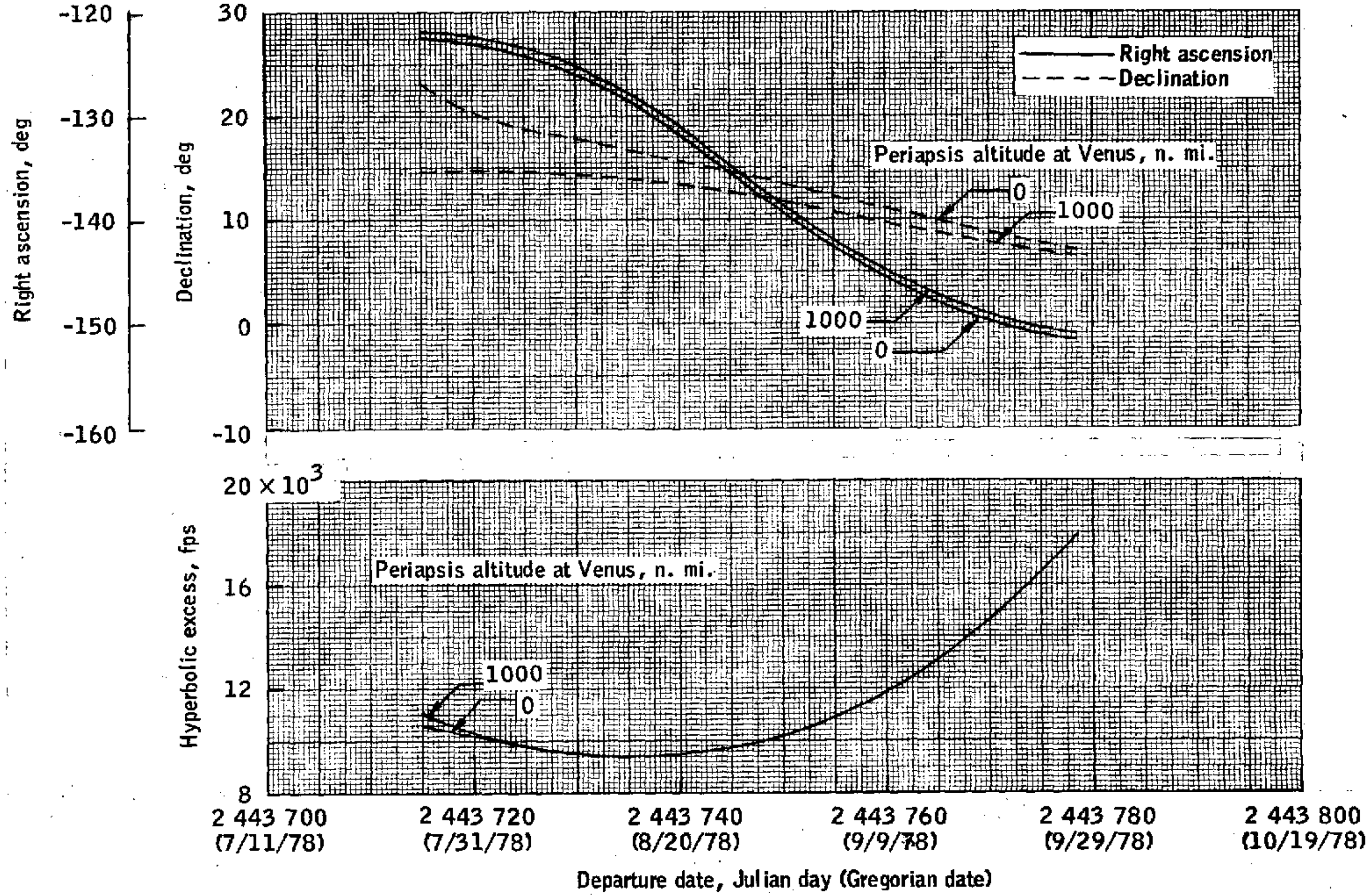
(a) Injection velocity and entry velocity at Earth.

Figure 3.- Characteristics of free-return trajectories to Venus between July 11, 1978 and October 19, 1978.



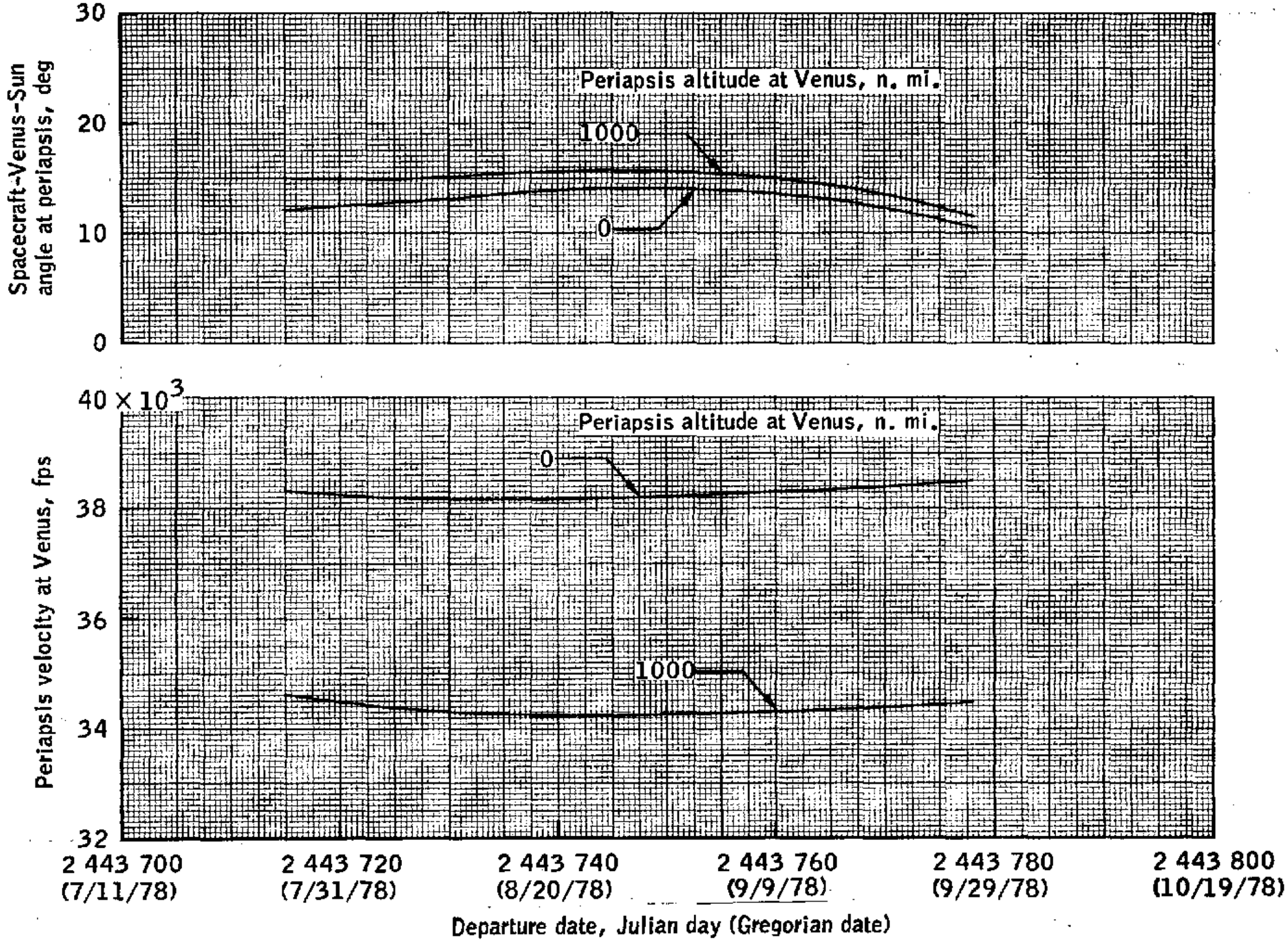
(b) Outbound trip time and total trip time.

Figure 3.- Continued.



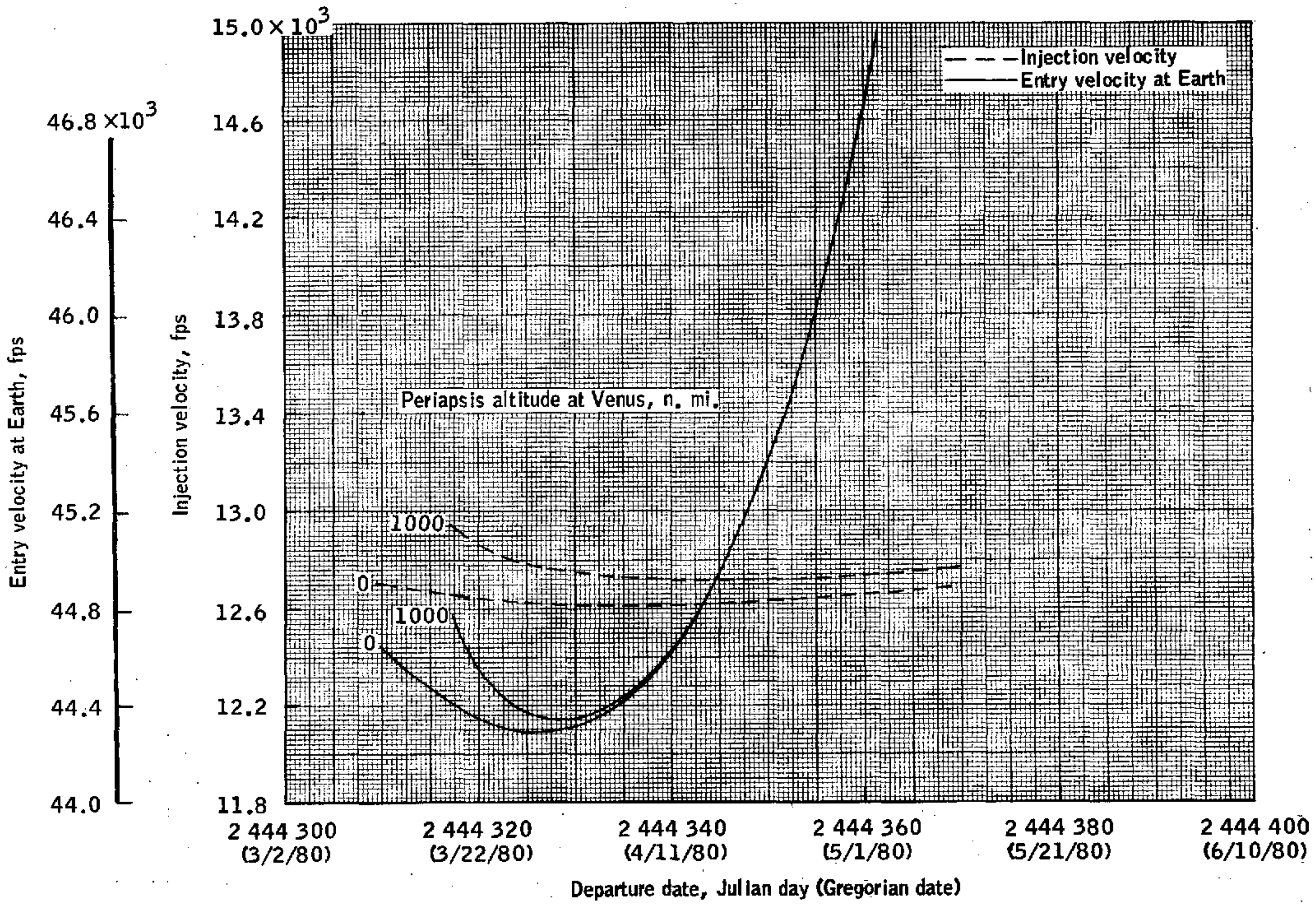
(c) Direction and magnitude of hyperbolic excess vector at departure from Earth.

Figure 3.- Continued.



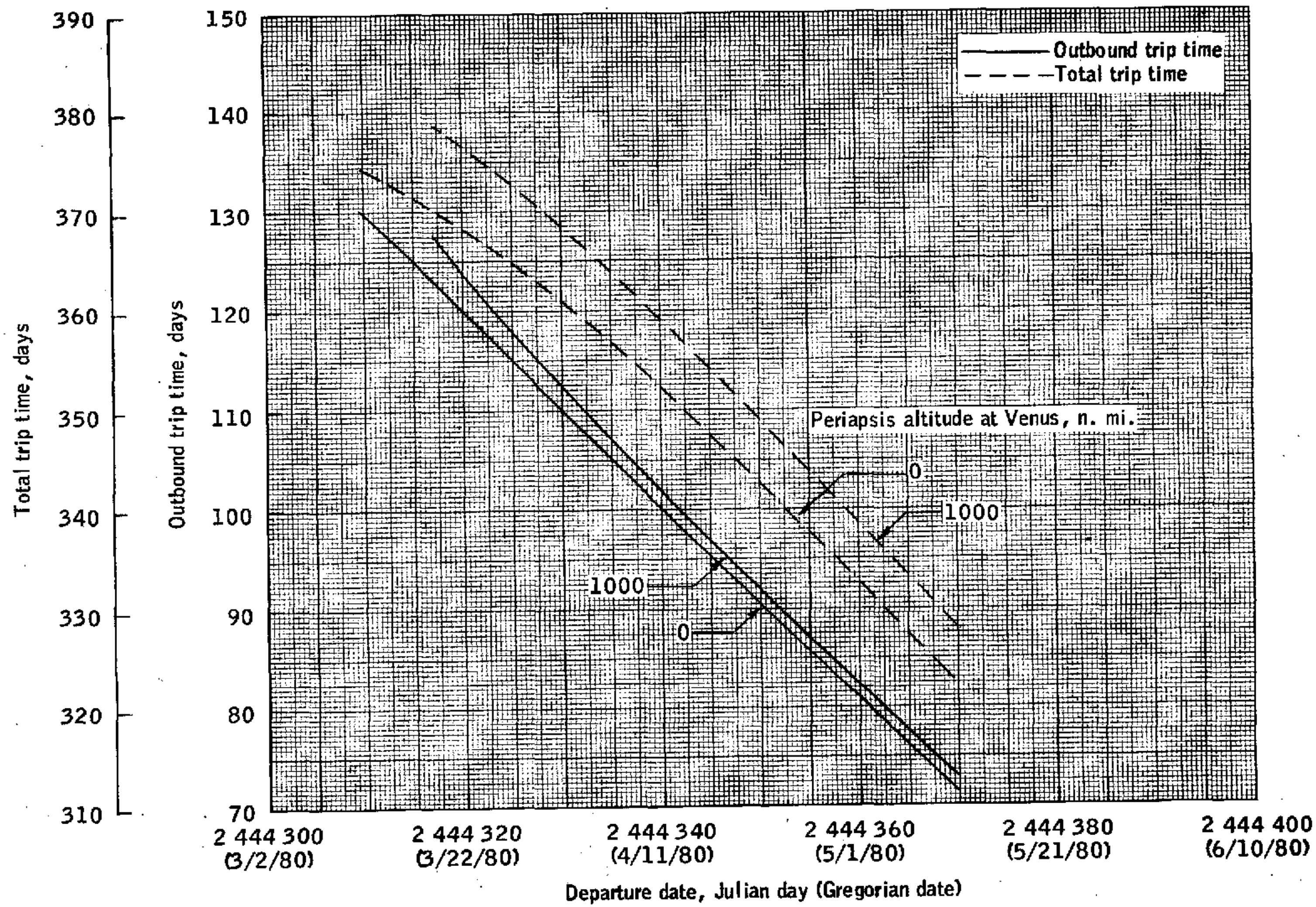
(d) Periapsis velocity at Venus and spacecraft-Venus-Sun angle at periapsis.

Figure 3.- Concluded.



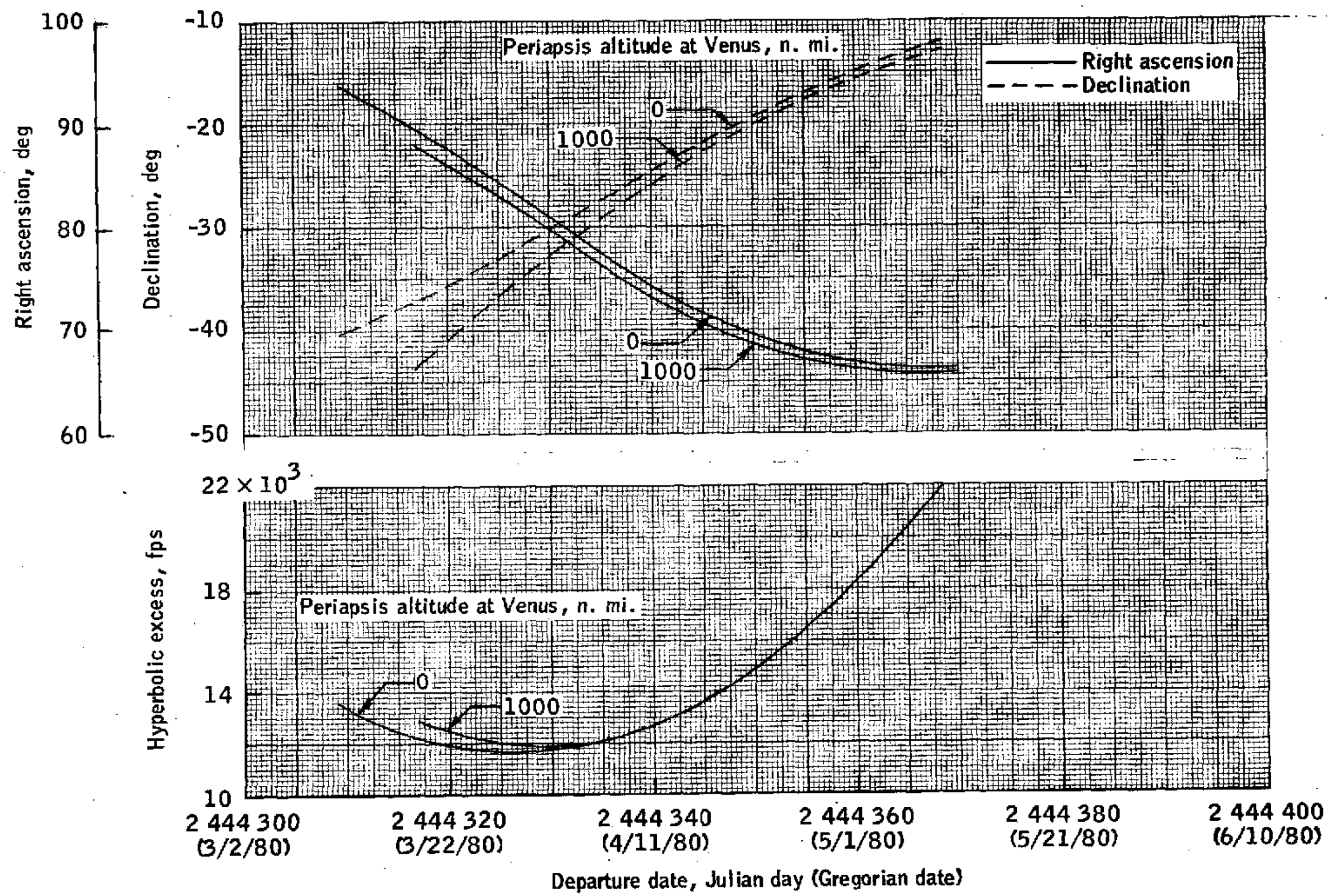
(a) Injection velocity and entry velocity at Earth.

Figure 4.- Characteristics of free-return trajectories to Venus between March 2, 1980 and June 10, 1980.



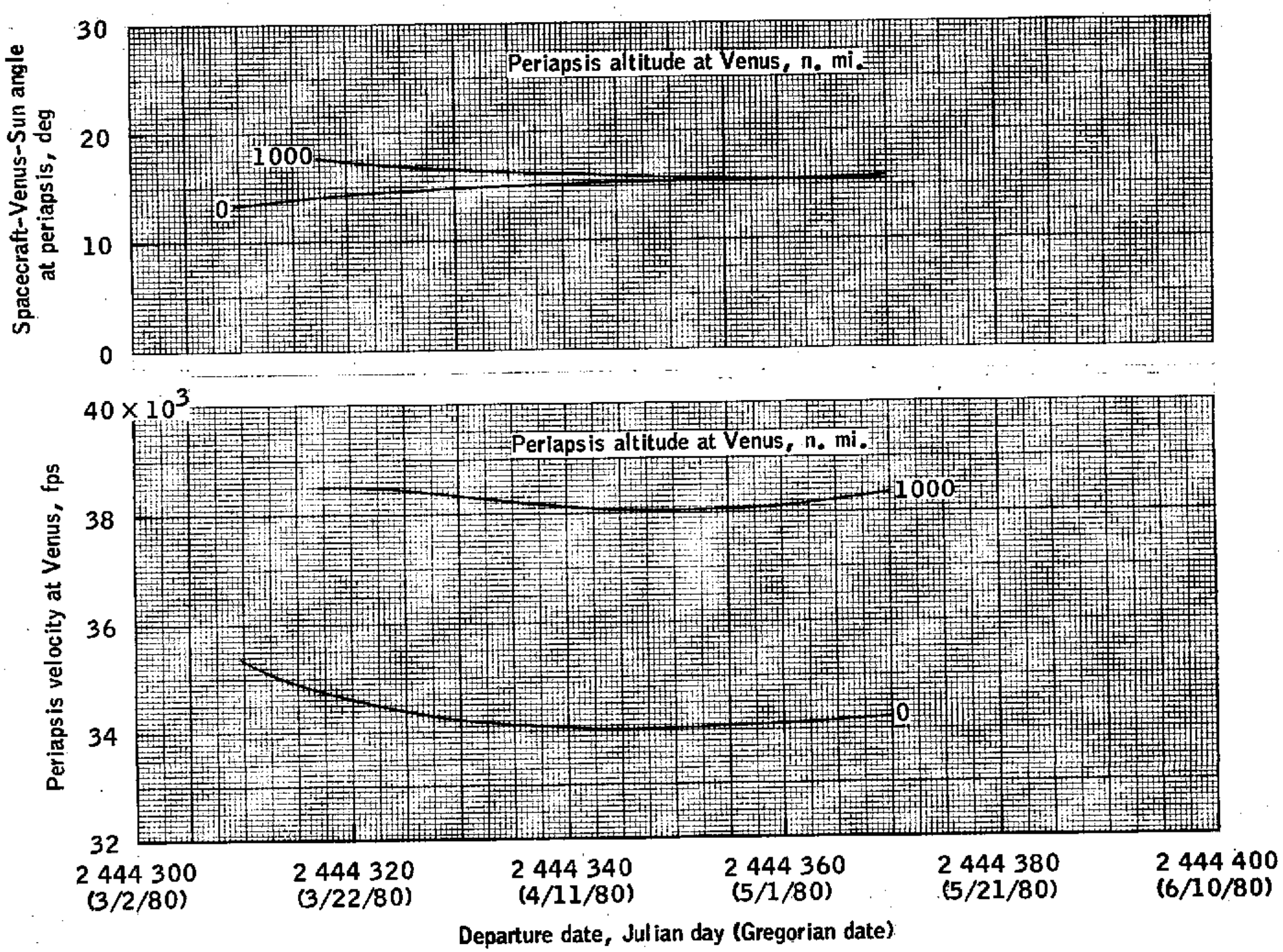
(b) Outbound trip time and total trip time.

Figure 4.- Continued.



(c) Direction and magnitude of hyperbolic excess vector at departure from Earth.

Figure 4.- Continued.



(d) Periapsis velocity at Venus and spacecraft-Venus-Sun angle at periapsis. June 10, 1980.

Figure 4.- Concluded.

REFERENCES

1. Garland, Benjamine J.: Free-Return Trajectories to Venus Between 1970 and 1975. MSC IN 67-FM-14, February 3, 1967.

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4. Anon.: Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac. Government Printing Office, Washington, D.C., 1961.

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